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HIGH-ENERGY SOLAR X-RAYS OF 7 JULY 1966

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AND
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GODDARD SPACE FLIGHT CENTER
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Abstract: The time history and differential intensity of solar X-rays of energies from 80 to more than 500 KeV were observed during the flare event of 7 July 1966. These measurements, made from a solar-oriented stable platform on OGO-III, cover the highest differential energy range studied thus far and indicate the greatest intensity in hard X-rays of any solar event observed to date. Three intensity peaks occurred at about 0027, 0029 and 0037 UT, coinciding with the times of microwave and optical intensity maxima. A study of the spectral and temporal characteristics of the X-ray emission, and comparison with the radio and optical data, indicate a non-thermal bremsstrahlung origin for the X-rays.

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1. Introduction

Solar X-ray bursts of photons with energy below 200 KeV have been observed from balloons and satellites for nearly a decade, with the consensus of opinion attributing the hard X-radiation to non-thermal bremsstrahlung processes in the flare region (deJager, 1). This type of mechanism was first proposed by Peterson and Winckler (2). More recently, it has been suggested that all of the observations of energetic flare X-rays to date may be explained in terms of the bremsstrahlung of thermal electrons (Chubb, et al., 3). The measurements presented here were made over a somewhat higher energy interval, 80 KeV to 1 MeV, during the first high-intensity flare of the new solar cycle, that of 7 July 1966. They appear to be much more easily reconciled to the non-thermal bremsstrahlung hypothesis.

2. Apparatus

The reported data were obtained from a low-energy positron detector incorporating two X-ray spectrometers (Cline and Hones, 4). This detector, shown schematically in Figure 1, was designed primarily to search for interplanetary positrons by measuring the spectra of single or paired X-rays accompanying stopping particles. In one of the possible modes of data acquisition, single X-rays may be monitored in one of the CsI spectrometers with 4π particle anticoincidence which is virtually X-ray transparent above 80 KeV. Once each 18.5 seconds, integral intensity measurements are made in each of the 16 energy levels equally spaced between 80 KeV and 1 MeV, allowing for both temporal and spectral analysis of the data. During the event reported here the detector was mounted on the solar panel of OGO III. It was continuously pointed at the sun, was well outside the region of geomagnetic influence, and enjoyed uninterrupted data recovery. In-flight calibration of the spectrometer was accomplished by monitoring the 511 KeV annihilation line.

3. The 7 July 1966 Event

This event was not only unusually intense in hard X-rays, but was reported at Nagoya (5) as very intense in microwave radio emission and, in addition, was found to be the first known event in which a detectable intensity of relativistic solar electrons was found in interplanetary space (Cline and McDonald, 6).

The solar H_α flare of importance 3 was observed at N35, W48 in McMath plage region 8362 starting at 0025 UT. The optical flare coincided approximately with the radio burst, a complex type IV observed over a wide frequency range. The dynamic spectrum shown in Figure 2, compiled by Hakura (7) using data from Nagoya, Penticton and Hiraiso, has intense microwave bursts at about 0027, 0030 and 0038 UT ascribed to the synchrotron radiation of electrons in the sunspot field, followed by radiation peaking in intensity at longer wave lengths from about 0100 to 0200 UT related to electrons in the higher corona.

4. X-Ray Results

The time history of X-rays of energy greater than 80 KeV is shown in Figure 3. The intensity maxima at about 0027, 0029 and 0037 UT correlate well with the microwave bursts. The third maximum corresponds to more than 300 photons cm^{-2} sec^{-1} above 80 KeV at its peak. This excellent X-ray-microwave correlation has been pointed out previously by Kundu (8) at somewhat lower X-ray energies. The spectrum of detectable X-rays extends up to several hundred KeV, exhibiting the same three maxima at the same times. This intense emission over such a large range of energies, from microwave radiation to quanta of nearly an MeV, with repetitive bursts exhibiting excellent temporal correlation, seems indicative of a non-thermal model for the X-ray generation.

The observed integral X-ray spectrum in the main peak, corrected for detector inefficiencies, is shown in Figure 4. This correction is negligible at 80 KeV, but the detector is only about 25% efficient at 500 KeV. The spectrum is shown compared with that computed for a sample of isothermal origins, and is seen to be incompatible with bremsstrahlung generation from an optically thin isothermal region. Note that the experimental spectrum gets increasingly harder at higher energies, while an isothermal bremsstrahlung source would get increasingly softer. It may be fitted, of course, to a superposition of multiple isothermal spectra having temperatures up to more than a billion degrees, but this procedure is too arbitrary to be definitive. Both the extremely high temperatures required by any multithermal model to match the experimental spectrum, and the rapid heating and cooling demanded by the time characteristics would seem to argue against a thermal mechanism.

As a measure of the relative shape of the spectrum in time, we have calculated the best power law fit to the first three integral levels (80, 136 and 203 KeV) as a function of time (pre-event background has been subtracted out, of course). This is shown in Figure 5. The gradual flattening of the spectrum in time is again suggestive of non-thermal bremsstrahlung. In contradistinction, Chubb et al. (3) find a steepening of the spectral shape in time for the flares of 31 August 1959 and 1 September 1959 which they attribute to the cooling of an isothermal plasma.

5. Conclusions

The spectral shape, time characteristics and radio correlation for the flare of 7 July 1966 strongly suggest a non-thermal bremsstrahlung origin for the hard X-rays. It is important to note, however, that the NRL data for the 1959 events have very different spectral and temporal characteristics (which have been interpreted in terms of rapidly cooling isothermal plasma bremsstrahlung). It is entirely conceivable that the X-ray production in different flares may be governed by different mechanisms. The suggestion of Chubb et al. (3) that the observations of Peterson and Winckler (3) and Anderson and Winckler (9), originally attributed to non-thermal bremsstrahlung emission, be reinterpreted in terms of a thermal mechanism is well taken, since a thermal hypothesis can account for the observations (although multiple-temperature analysis is required). In the light of the present study, however, the attribution of hard flare X-rays to a thermal model in general would not be justified.

6. Acknowledgments

We wish to thank many persons connected with the success of the OGO III satellite. In particular, G. Porreca provided a great deal of assistance in the design, testing and calibration of the detector package

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Figure Captions

1. Schematic representation of the X-ray spectrometer.
2. Dynamic radio spectrum for the solar event of 7 July 1966.
3. Time history of X-rays above 80 KeV for event of 7 July 1966. For purposes of time correlation, the 17,000 mc/sec data of T. Takakura and H. Tanaka are displayed together with the X-ray data (10).
4. Integral spectrum of solar X-rays of 7 July 1966. The solid lines represent the emission expected from isothermal sources, normalized such that they coincide with the 80 KeV point on the experimental spectrum.
5. Best power law fit to the lowest three points on the experimental integral X-ray spectrum (80, 136 and 203 KeV) as a function of time for 7 July 1966. The power law is calculated for the large maximum for times when the counting rate is larger than that observed in the two smaller maxima. Each point represents the average for four consecutive readouts.

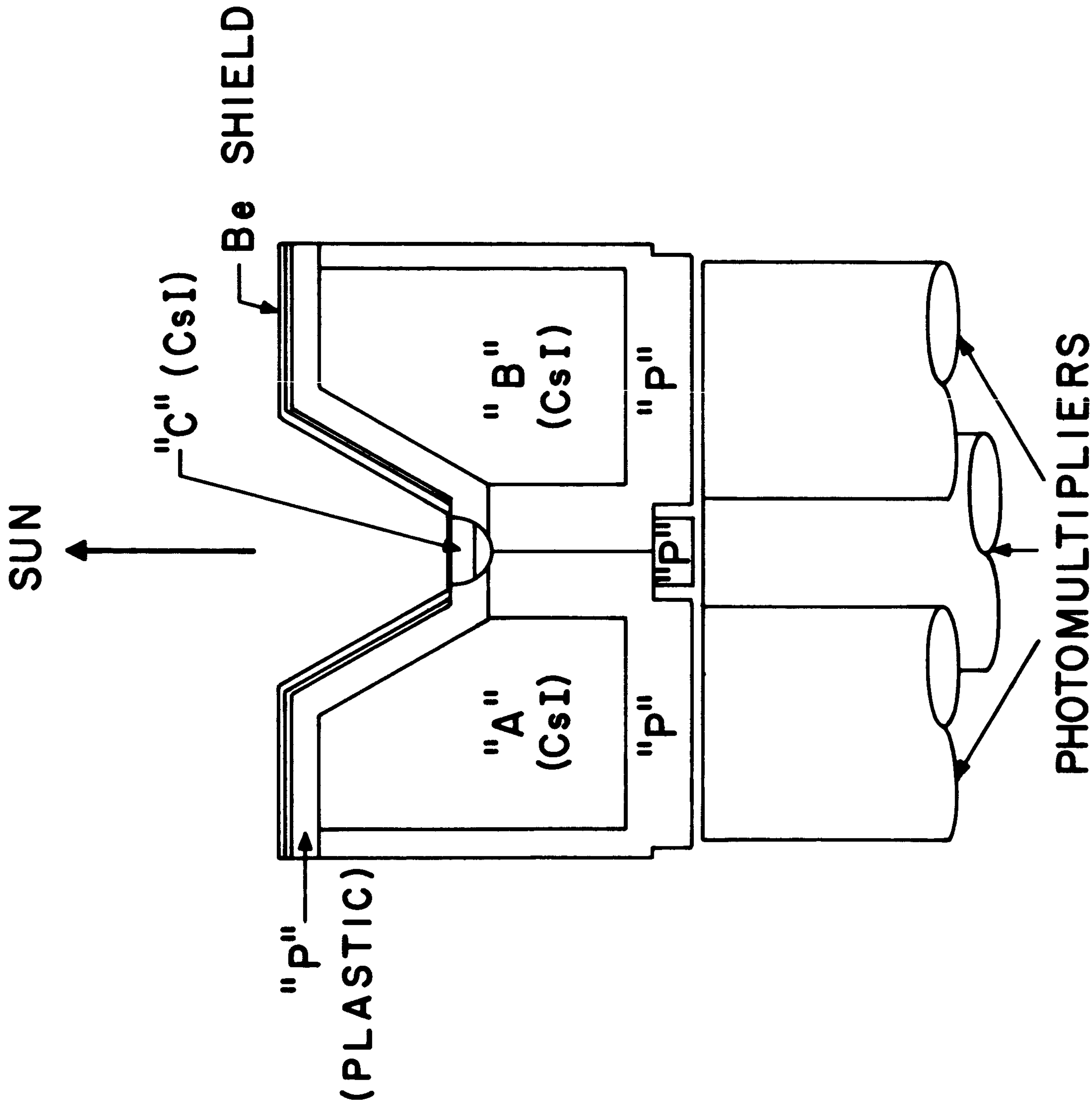

SUN
"C" (CsI)
Be SHIELD
"B" (CsI)
"A" (CsI)
"P"
"P"
"P"
"P" (PLASTIC)
PHOTOMULTIPLIERS

Fig. 1.

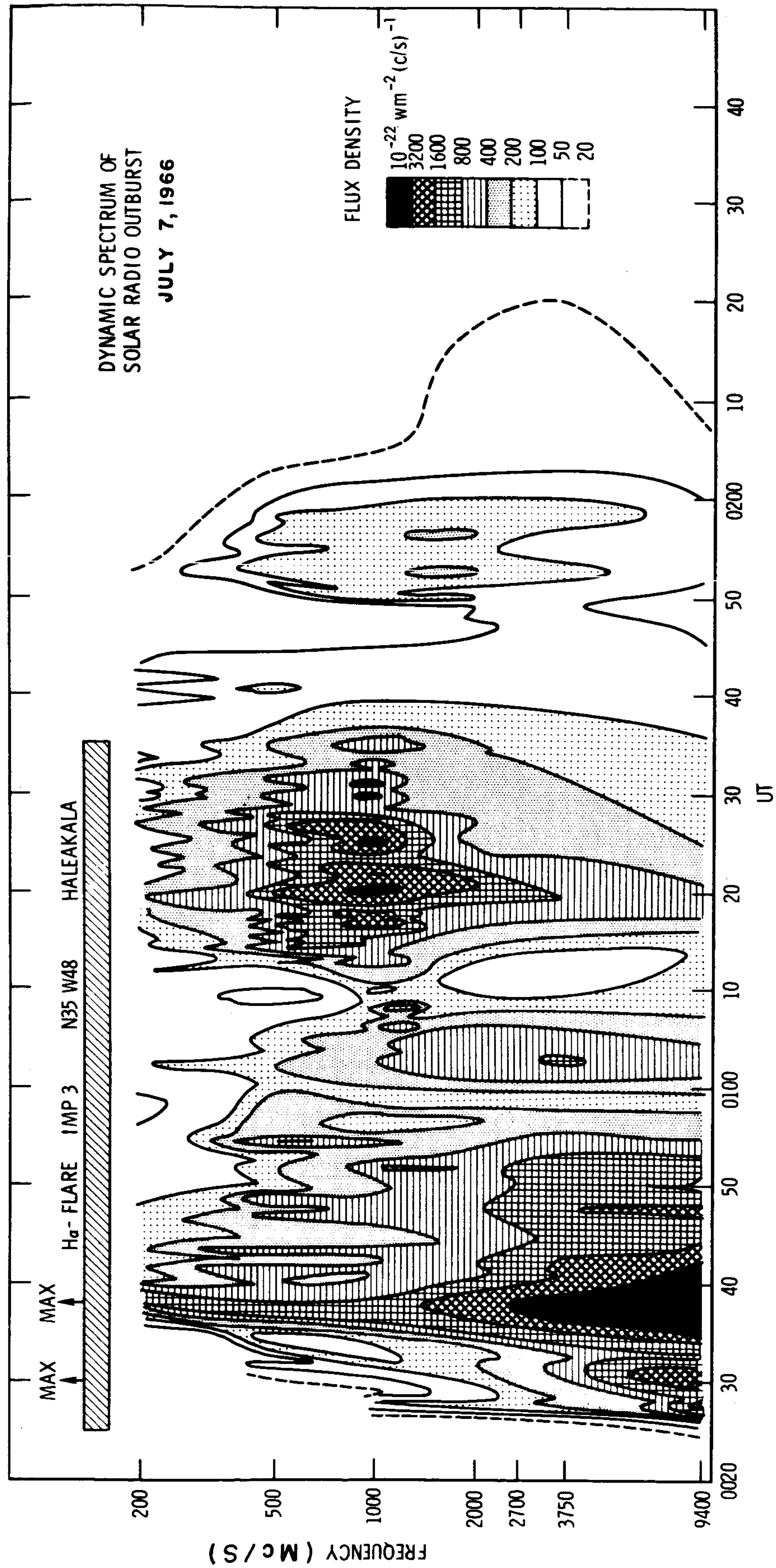
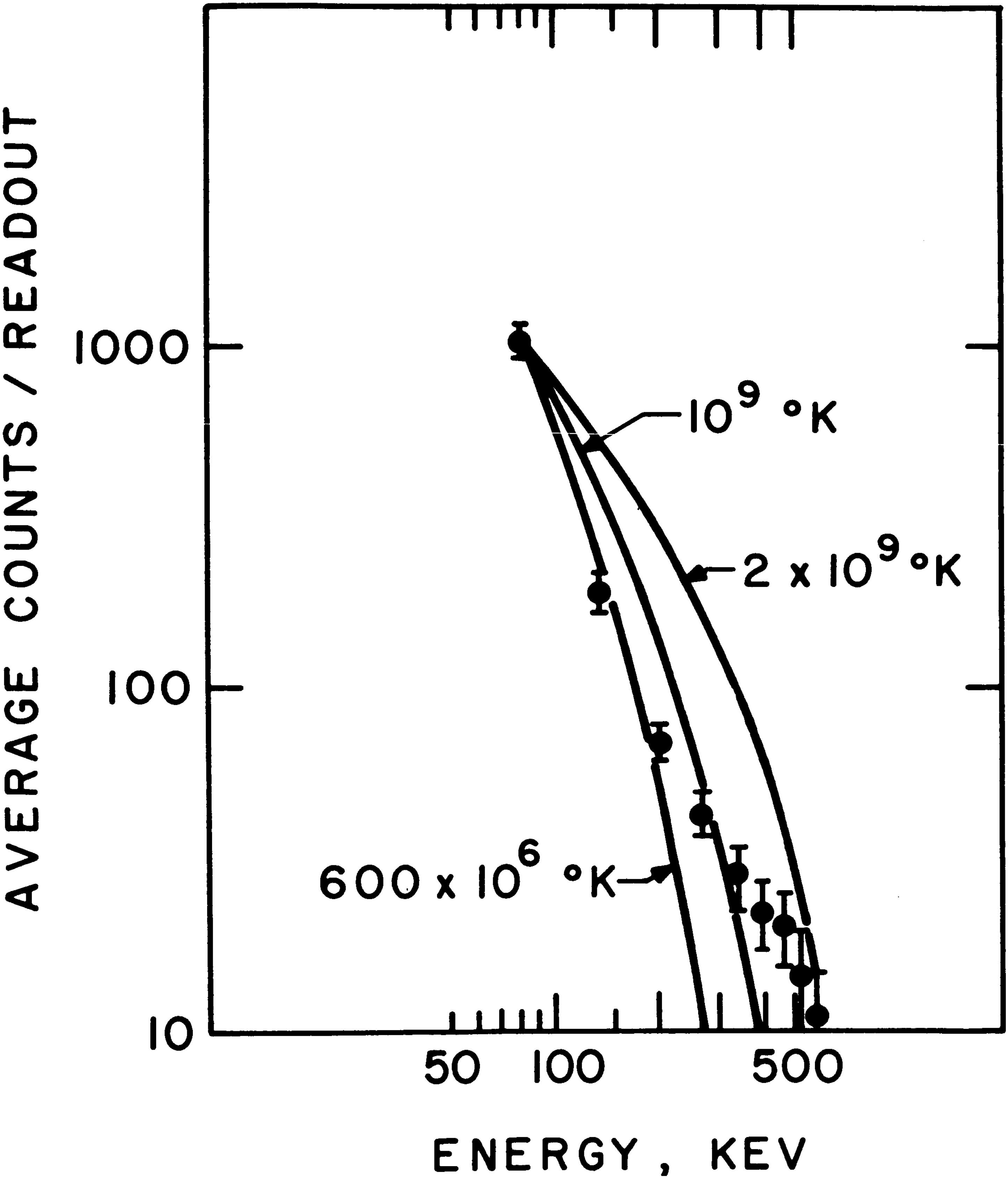

DYNAMIC SPECTRUM OF
SOLAR RADIO OUTBURST
JULY 7, 1966
FLUX DENSITY
10^{-22} wm^{-2} (c/s)$^{-1}$
3200
1600
800
400
200
100
50
20
MAX
MAX
Hα- FLARE IMP 3 N35 W48 HALEAKALA
UT
0020
30
40
50
0100
10
20
30
40
50
0200
10
20
30
40
FREQUENCY (Mc / S)
200
500
1000
2000
2700
3750
9400

Fig. 2.



AVERAGE COUNTS / READOUT
1000
100
10
10^9 °K
2×10^9 °K
600×10^6 °K
50
100
500
ENERGY, KEV

Fig. 4.

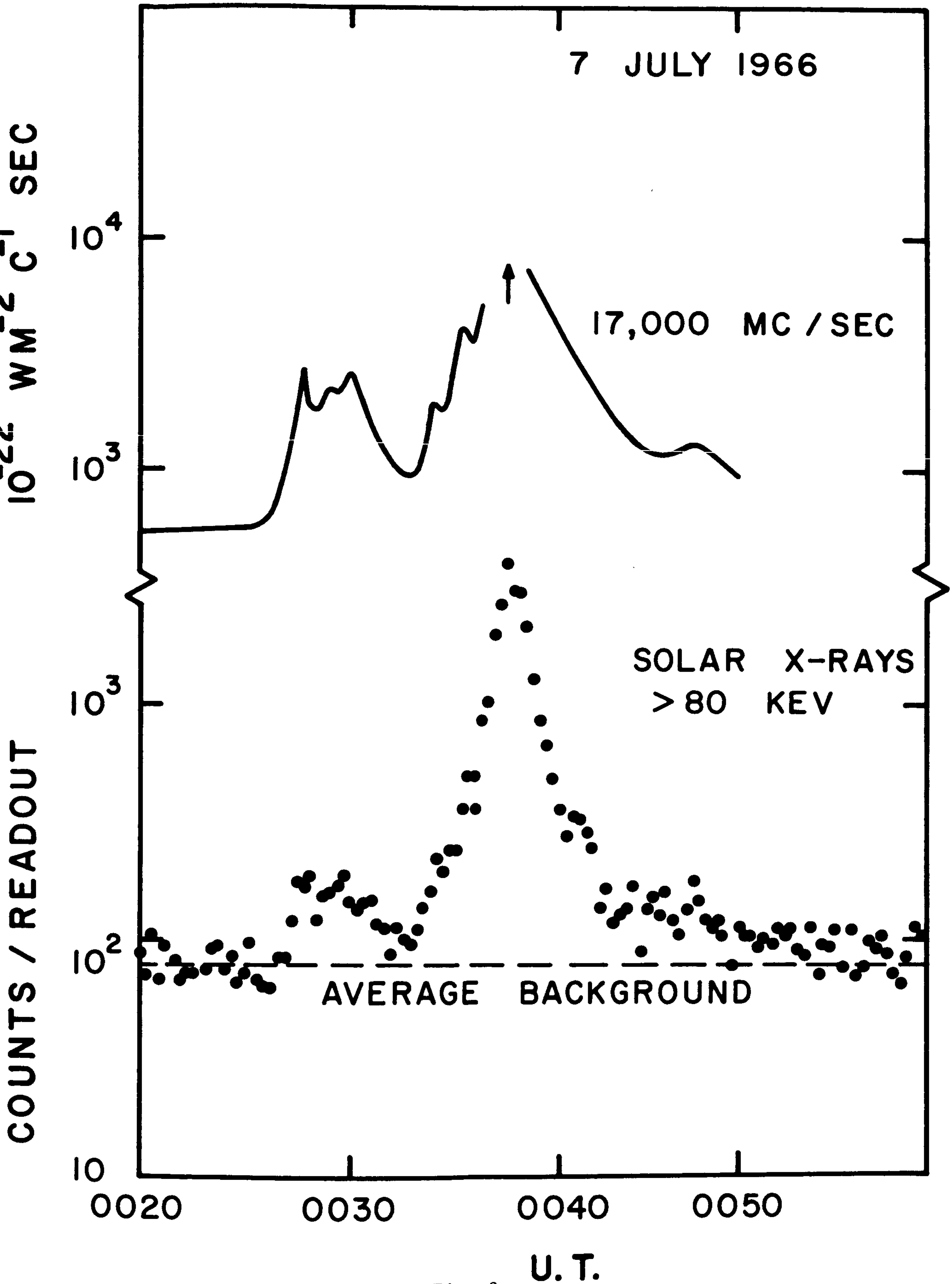

7 JULY 1966
10^{-22} WM^{-2} C^{-1} SEC
10^4
10^3
17,000 MC / SEC
SOLAR X-RAYS
> 80 KEV
10^3
10^2
10
COUNTS / READOUT
AVERAGE BACKGROUND
0020
0030
0040
0050
U.T.

Fig. 3.

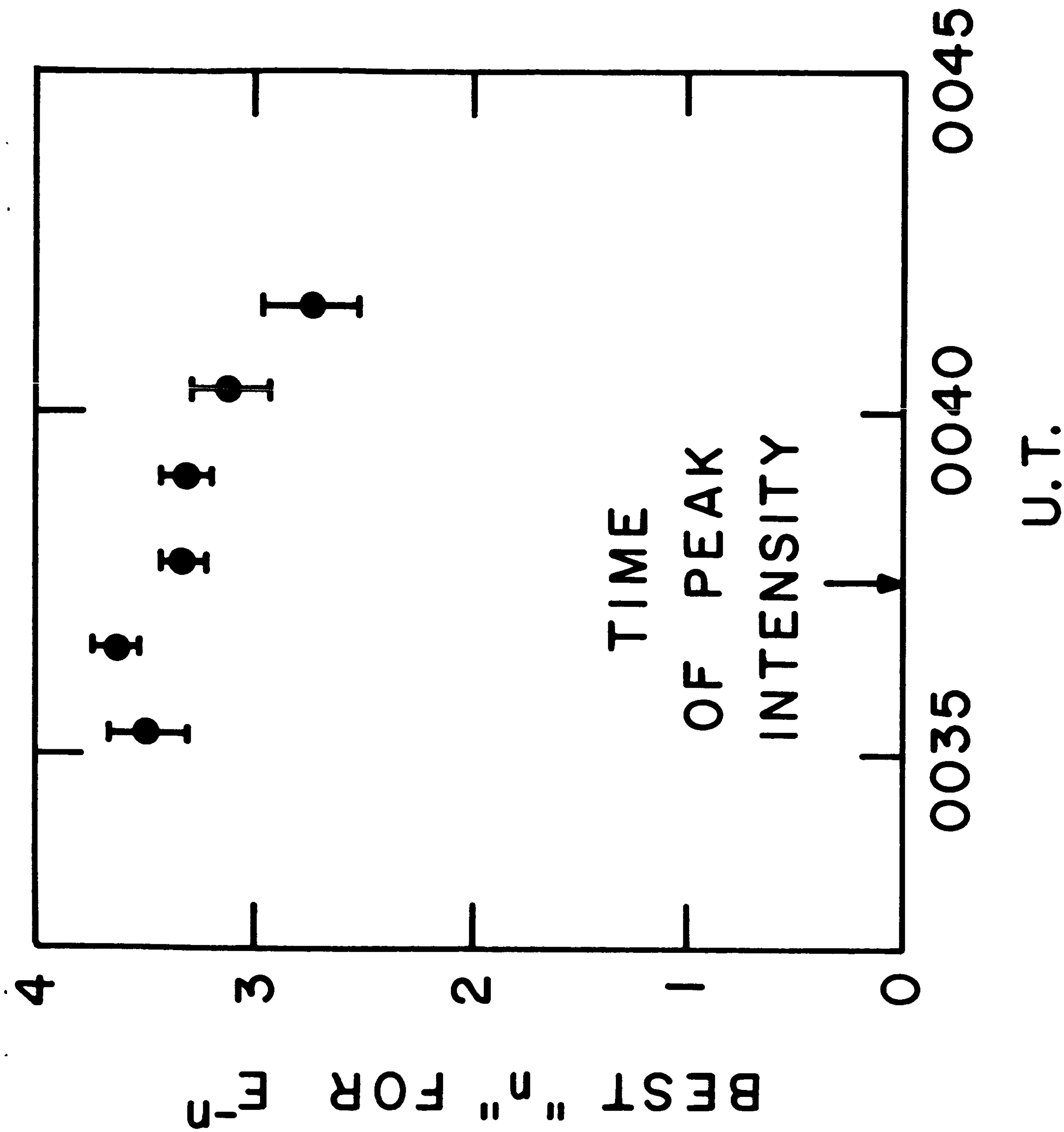


Fig. 5.